Energy Efficient Multipath Data Fusion Technique for Wireless Sensor Networks

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***Abstract*—In wireless sensor networks (WSN), data fusion should be energy efficient. But, determining the optimal number of aggregators in an energy efficient manner is a challenging task. Moreover, the existing data fusion techniques mostly use the same path for transmitting aggregated data to the sink which reduces the nodes lifetime. In this paper, we propose a technique which combines energy efficiency and multiple path selection for data fusion in WSN. The network is partitioned into various clusters and the node with highest residual energy is selected as the cluster head. The sink computes multiple paths to each cluster head for data transmission. The distributed source coding and the lifting scheme wavelet transform are used for compressing the data at the CH. During each round of transmission, the path is changed in a round robin manner, to conserve the energy. This process is repeated for each cluster. From our simulation results we show that this data fusion technique has less energy consumption with increased packet delivery ratio, when compared with the existing schemes.**

***Index Terms*— wireless sensor networks (WSN), Data Fusion Techniques, distributed source coding (DSC), Modified Unary Coding (MUC), Energy Efficient Fusion Techniques.**

I. Introduction

A. Data Fusion in Wireless Sensor Networks

In sensor networks, data fusion is an essential service. In order to compute useful information, such as average of all the sensor readings, the maximum value among the sensor readings or the number of sensors that detect an event the data fusion process aggregates the data from independent sensors. [1] By eliminating redundancy and power consumption in data fusion, the performance of a network can be increased. This is because the fault-tolerance between the sensors is ensured and the available communication bandwidth between network components is effectively managed. [2]

For the purpose of energy-efficient information flow from several sensors to a central server or sink, in-network data fusion is needed in wireless sensor networks. To effectively fuse the data, the data fusion techniques should be synchronized at various levels. The credibility of the aggregated report can be increased, by fusing the information from as many sensors as possible. [3] On considering the measurements of multiple sensors, the system performance can be improved in data fusion which is a widely adopted signal processing technique. Enabling collaboration among the sensors improves the system sensing performance effectively. [4]

B. Existing Data Fusion Techniques in Wireless Sensor Networks

- *Witness based data fusion:* In the witness based data fusion, the data fusion node doesn't forward its result to the base station but will compute the Message Authentication Code (MAC) of the result (they call the MAC a proof). After receiving this information the data fusion node forwards the proofs to the base station. The data fusion node has to create false proofs on the invalid result if the node has to be compromised and wanted to send an invalid fusion result to the base station. [5]
- *Dynamic data fusion:* In sensor networks, the dynamic application specified data fusion is supported by an architectural framework known as DFuse. The dynamic nature of applications in sensor networks is considered by the advanced fusion applications. This dynamic data fusion bridges an important abstraction gap for developing these applications.
- *Multi-sensor data fusion:* Diverse sensors like temperature, humidity light, and Carbon Monoxide are set in each sensor node. The information about the environmental condition can be provided by using more than one sensor. The fuzzy rule based system helps in processing and fusion of these diverse sensor signals. [6]
- *Single Mobile agent (MA)-based autonomic data fusion:* Here for autonomic data fusion, only one MA is used. In small scale WSNs this approach is effective but in the networks comprising hundreds or thousands of sensor nodes these solutions doesn't scale acceptably.
- *Multiple MA-based autonomic data fusion:* In order to fuse the data from WSN sensors, in this approach number of MAs are working parallel. Large scale WSNs also supports this fusion technique. The itineraries of individual MAs are derived using the relatively complex algorithms. [7]
- *Mobile agent based clustering data fusion*: In this data fusion, two cluster head models are used to control the size of the clusters. All the sensor nodes in the detection region are divided into several clusters and the fault nodes are removed through the partial results of data integration. The mobile agents are used in between the cluster heads for data fusion, and the path of the mobile agent is optimized. [8]

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C. Need for Power Efficient Data Fusion in Wireless Sensor Networks

- The redundancy among sensed data and the network load can be reduced by exploring data correlation and employing in-network processing. [9]
- Though the wireless sensor networks have infinite scopes, they have limited node battery lifetime. When there is sufficient battery power, the network can be operated after deployment. Once a battery is deployed over an inaccessible area it is impossible to replace the node battery and this problem needs to be considered mainly. [10]
- Failures often occur in wireless sensor networks, since they are not considered for long periods of time in the field. Sensors running out of energy, ageing or harsh environmental conditions surrounding them are the reasons for these failures. [11]
- The sensor nodes must rely on small, usually non-renewable batteries, energy efficiency is considered as a most important design concern in sensor networks. Consumption of energy in a sensor node is processed in data acquisition, processing and communication. The data transmission among the sensor nodes is reduced to a minimal level since the transmit power is governed in many of the applications. [12]
- Due to limited detection range and reliability of each node, we need to make the monitoring range overlap each other, so that the accuracy and robustness of the network can be enhanced. Therefore, the data in the sensor nodes maintains certain redundancy. The redundant information should be reduced and the energy has to be saved to prolong the network lifetime and so each node transmits its detection data to the sink node in the routing. [8]
- The cost and continual power consumption of sensors are high since extra circuits are required in hardware based approach in order to detect or frustrate the compromised node. [13]

D. Problem Identification and Solution

In Wireless Sensor Networks (WSN), the data fusion should be energy efficient. But the existing data fusion techniques mostly use the same path for transmitting aggregated data to the sink, which results in reduced lifetime of the nodes along the paths. Moreover, determining the optimal number of aggregators in an energy efficient manner is a challenging task.

Here, we propose a technique which combines the energy efficiency and the multiple path selection for data fusion in WSN. We assume multiple paths from each cluster to the sink. Initially, the nodes form a cluster and the number of aggregators that minimizes the total energy consumed by transmitting and aggregating data is determined. Each sensor selects the closest aggregator as its cluster head. Then the sensors send packets to their respective aggregator. Each aggregator compresses the data it receives from the sensors of its cluster and finally forwards the data to the sink.

In the initial round, from the aggregators, the aggregated data is transmitted to the sink using one of the established multiple paths. During each round of transmission, the path is changed in a round robin manner, to conserve the energy. This process is repeated for each cluster.

Thus this data fusion technique is energy efficient and involves multiple paths for transmission of data.

II. Related Work

Frank Yeong-Sung Lin et al [14] have proposed this paper which considers the energy consumption tradeoffs between data aggregation and retransmissions in a wireless sensor network. By using the existing CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) MAC protocol, the retransmission energy consumption function is well formulated. This paper proposes a novel non-linear mathematical formulation, whose function is to minimize the total energy consumption of data transmission subject to data aggregation trees and data retransmissions.

Rabindra Bista et al [15] have proposed a new energy balanced and efficient approach for data aggregation in wireless sensor networks, called Designated Path (DP) scheme. In DP scheme, a set of paths is pre-determined and run them in round-robin fashion so that all the nodes can participate in the workload of gathering data form the network and transferring the data to the sink node. They use Semantic Routing Tree (SRT) for disseminating any kind of aggregation query to get aggregated value.

V. Bhoopathy et al [16] have proposed Energy Efficient Secure Data Aggregation Protocol. First the network is divided into clusters, each cluster is headed by an aggregator and the aggregators are connected to sink either directly or through other aggregators. The aggregator is selected based on the nearest distance to a set of sensor nodes and its energy level. Separate keys are distributed to the two levels i.e., sensor node to the aggregator and aggregator to the sink. Whenever a sensor node wants to send data to another node; first the sensor node encrypts the data using a key and sends it to the aggregator. For integrity of the data packet, a MAC based authentication code is used.

Yuanzhu Peter Chen et al [17] have proposed an Energy-Efficient Protocol for Aggregator Selection (EPAS). Then, they generalize it to an aggregation hierarchy and extend EPAS to a Hierarchical Energy-Efficient Protocol for Aggregator Selection (hEPAS). They derive the optimal number of aggregators with generalized compression and power consumption models, and present fully distributed algorithms for aggregator selection.

M. Umashankar et al [18] have proposed a novel power-efficient data fusion assurance scheme using silent negative voting mechanism and data fusion assurance with random key pre-distribution scheme has been proposed. The proposed schemes has been compared and evaluated their efficiency with a simple MAC based fusion assurance scheme as well as the direct voting based fusion assurance scheme.

Huseyin Ozgur Tan et al [22] have proposed localized power efficient data aggregation protocols (L-PEDAPs) for wireless sensor networks. Their protocol is based on topologies such as local minimum spanning tree (LMST) and

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relative neighborhood graph (RNG). Their solution involves route maintenance procedures and it is also adapted to consider the remaining power levels of nodes in order to increase the network lifetime.

D. Kumar et al [23] have proposed a novel Energy Efficient Clustering and Data Aggregation (EECDA) protocol for the heterogeneous WSNs. This protocol includes a novel cluster head election technique and a path would be selected with maximum sum of energy residues for data transmission instead of the path with minimum energy consumption.

Hasan Cama et al [24] have proposed energy-efficient secure pattern based data aggregation (ESPDA) for wireless sensor networks. ESPDA prevents the redundant data transmission from sensor nodes to cluster-heads. They have also presented a security protocol and NOVSF block-hopping technique that provides data communication security.

Mohamed Watfa et al [25] have proposed an energy-efficient approach to query processing by implementing new optimization techniques applied to in-network aggregation. They did not concentrate on the data routing strategies and loss tolerance mechanism.

Xu Li et al [26] have proposed a novel two-stage delay model based on IEEE 802.11 CSMA/CA MAC layer. This model uses hop count to measure end-to-end delay when the network traffic is low, and degree sum along the routing path when the traffic is high. They introduced the novel concept of DEsired Progress (DEP) for hop selection and devised a localized delay-bounded and energy-efficient data aggregation (DEDA) protocol accordingly.

Siddhartha Chauhan et al [27] have proposed an energy efficient data gathering protocol (EEDGP) for wireless sensor network. This protocol reduces the transmission of the data packets thereby reducing the energy consumption of sensor nodes.

Mohammad Mostafizur Rahman Mozumdar et al [28] have proposed an efficient data aggregation algorithm for

Cluster-based sensor network. The proposed algorithm selects a cluster leader that will perform data aggregation in a partially connected sensor network. The algorithm reduces the traffic flow inside the network by adaptively selecting the shortest route for packet routing to the cluster leader.

III. Proposed Work

A. Cluster Head Selection and Data Transmission

In this technique, we select the node with highest residual energy as the cluster head in order to prolong the lifetime of the network. We randomly consider few nodes as the initiator nodes (I) to collect the information of the nearest sensor nodes and to select the cluster heads depending upon the energy information.

We assume that in this sensor network, the sink node has the knowledge about all other node's location. The sensor nodes are assumed to be immobile and have limited energy.

The initiator node (I), determines the CH based upon the residual energy of the nodes. In a homogeneous network, cluster head uses more energy than non cluster head nodes. When the energy of the cluster head goes down, the network performance degrades. In order to balance the network energy consumption, the clustering needs to ensure that energy dissipation across the network should be balanced and cluster head should keep on changing.

- The initiator I broadcasts a request message for energy (E_{REQ}) with its own energy level (RL_{ini}) information to its surrounding nodes.
- The sensor node S_i compares its own energy level (RL_i) with the initiator.
- If $RL_i > RL_{ini}$, then,

  sends a reply message for energy (E_{REP}).

  Else

waits for cluster head advertisement messages. (CH_{ADV}) .

- The initiator selects the cluster head with maximum residual energy and the next initiator node is the node having the second maximum residual energy.
- The initiator node is changed every time when the energy level of the node decreases.
- After CH is selected by the initiator, clusters are formed in the network.
- The nodes in the cluster broadcasts a CH_{ADV} to the CH and CH sends it to the sink along with the cluster ID.
- A join request message J_{REQ} is transmitted by the member node along with CH_{ADV}.

The transmission range gets minimized since the initiators collect the energy information about the nearest sensors. The nodes having energy greater than the energy level of the initiator ensure minimization of E_{REP} message transmission.

Once the selected cluster head node receives the J_{REP} message from member nodes, it sends a joint reply message J_{REP} back to the nodes. Then the CH transmits data to the sink node.

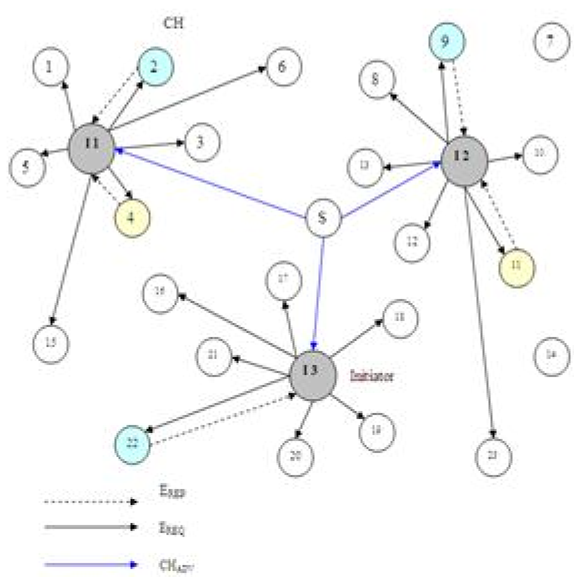

Figure 1. Selection of Cluster Head

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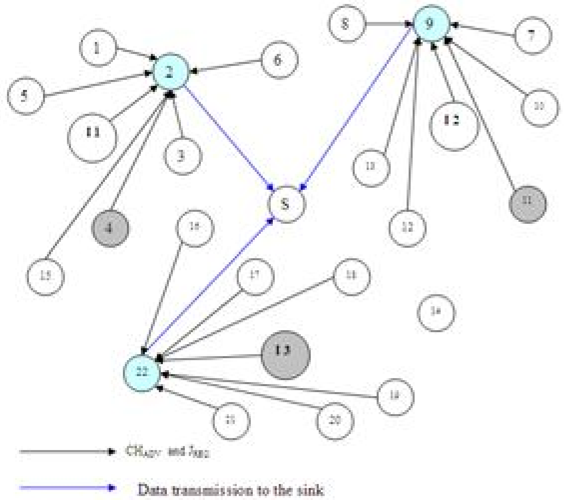

Figure 2. Data transmission from CH to Sink

In figure 1, the Initiator I1, I2, and I3 sends energy request E_{REQ} to all the surrounding nodes. For example, in this figure, when the node I1 sends E_{REQ} to the nodes, the energy consumption of the nodes is compared with I1. Since node 2 has a higher energy level than I1 and so node 2 is selected as the cluster head and node 4 which has the next highest energy level is selected as the next initiator for cluster head selection.

Similarly, when the node I2 sends E_{REQ} to the nodes, the energy consumption of the nodes is compared with I2. Here, node 9 has the highest energy level and it is selected as the Cluster head and the node 11 which has the next highest energy level is selected as the next initiator for cluster head selection.

Then when the node I3 sends to the surrounding nodes, the energy consumption of the nodes is compared with I3. Since node 22 has the highest energy level, it is selected as the cluster head and no other surrounding node has the next highest energy level other than initiator I3. So, we select node I3 as the next initiator node.

In figure 2, the data transmission from CH to the sink is described. After the selection of CH, the clusters are formed. The nodes in the cluster transmit CH_{ADV} with J_{REQ} to the CH. The CH then transmits this data to the sink.

B. Data Compression

The distributed source coding (DSC) is explained in the paper [19].

In WSNs we construct an algorithmic framework which supports DSC for high and low frequency signal compression. To preprocess the original data for signal decomposition and noise deduction, we use a lifting scheme wavelet transform **(**LSWT) in order to separate the low frequency component from the high frequency component, and strength the correlation among distributed sensor data. Compared to the traditional transforms, LSWT is better suitable for WSNs due to the following reasons:

1) Efficiency is higher compared to the FFT or DCT.

2) Time domain analysis is supported by transformed data.

3) Multi-scale analysis and integer to integer mapping are supported in LSWT.

The individual redundancy can be reduced by the scalar quantization after the LSWT process. The distributed redundancy is reduced when low frequency component of the sensor data is processed by DSC.

In the first step, we do the LSWT and it gets repeated by iteration on the S (even part of original data). A multi-level or multi resolution decomposition is created due to this.

In the next step, quantization, we reduce the individual redundancy by choosing a scalar quantization in our applications. For data compression combined with WT, quantization is widely studied and successfully implemented. The data values which have higher frequencies are set to zero after the quantization. The individual redundancy can be reduced significantly in the quantization process.

The high frequency data sets are encoded using the Modified Unary Coding (MUC). The nonzero values {Ai} are only encoded here.

$Ai > 0$:- encoding with $2 \times Ai$ bits 1 plus 10 bits relative position value.

$Ai < 0$:- encoding with $2Ai - 1$ bits 1 and 10 bits relative position value.

H(Y) is a sample value with n bits used for encoding the low frequency part when each value is mapped to the source codebook ranging from, 0 to2n-1. This is known as base data. The compress process ends and base data is sent to the base station when the data is collected from the sensor node else it will continue to the next step. The distributed redundancy is still more reduced by DSC after mapping. Portioning is done in the data set to split it into different cosets as the correlation of the data from neighbor layers. The fully compressed data is the original data value which is replaced with coset index represented by H(X|Y).

After compressing the data the base station collects these data. Decompression of all the data is done when the base station receives the collected data.

C. Multi path Routing from Cluster Head to Sink

For data transmission from CHs towards the sink node, multiple paths are created in the multi path discovery phase. These multi-paths are node disjoint. Due to the utilization of most available network resources, the multi-path routing usually prefers the node disjoint paths and thus they are fault tolerant. There is a minimum impact to the diversity of the routes since when an intermediate node in a set of node disjoint paths is failed, only the path containing that node gets affected.

The path discovery procedure is executed according to the following phases:

Initialization phase: The information about the neighbors having highest quality data is maintained by each CH since it broadcasts a HELLO message through the clusters. The neighboring table is maintained and updated in this phase. The knowledge about the list of neighboring nodes of the cluster head are maintained in the neighboring table. Hop count which represents the distance in hops for message from its originator is present in the HELLO message.

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Primary path discovery *phase:* The information on computing the cost function for CHs neighboring nodes is contained in the CH after initialization phase. After the preferred next hop CH is computed by the sink node an RREQ message is sent to the most preferred next hop. In the same way, the preferred next hop CH of the sink computes its most preferred next hop in the source node's direction. An RREQ message is sent to the next hop and the operation continues until the source node.

Alternative Paths discovery phase: The next most preferred neighbor is considered as the alternative path and the sink sends an alternate RREQ message to that neighbor. Each node accepts only one RREQ message in order to avoid having paths with shared nodes. When two or more nodes receive one RREQ message, the first RREQ message is only accepted rejecting the remaining messages.

For example in this figure 3, we compute multiple paths from the cluster head to the sink. The source node transmits the data to the cluster head CH4 and the CH4 wants to transmit the data to the sink. So, it computes four paths:

Path 1: Source-CH4-CH2-Sink
Path 2: Source-CH4-CH3-Sink
Path 3: Source-CH4-CH3-CH1-Sink
Path 4: Source-CH4-CH5-CH3-CH1-Sink

The best path is the path with minimum number of hops.

We select the path 1 (CH4-CH2-Sink) for transmission

When a failure occurs in that primary path the alternative path is selected. Path 2 (CH4-CH3-CH1-Sink) is chosen as the alternative path for further transmission. The path is changed in a round robin manner in order to conserve energy.

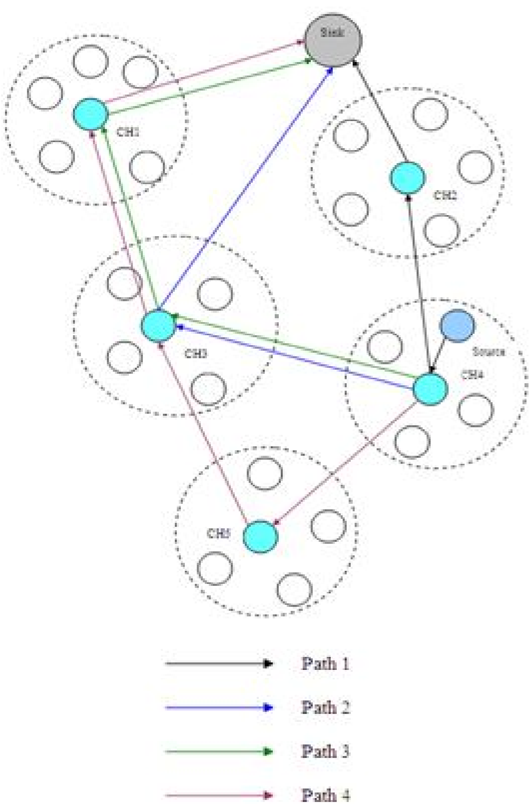

Figure 3. Multi-path clustering

D. Combined Algorithm

1. Among the N sensor nodes, randomly consider k nodes as the initiator nodes to collect the information.
2. The initiator I1 selects the cluster head based upon the energy level information.

For each neighbor Ni of I1 , $i = 1,2 \ldots r$

If $RL_i > RL_i > RL_{ini}$, then,

S_i sends a reply message for energy (E_{REP}).

Else

waits for cluster head advertisement messages .

End For

3. I1 select the node St as CH1 such that RLt = max{RLi},
4. CH1 broadcast a to Ni
5. Each node Ni sends request to CH1.
6. On accepting from the CH, nodes join the cluster.
7. Each CH send its cluster details to the sink.
8. The sink establishes multiple paths towards each CH and designates one path as the primary path.
9. At first cycle R1, sends the sensed data to its CH.
10. At CH, The data from its members is compressed using DSC.
11. CH sends the compressed data to the sink, using the primary path.
12. After the sink receives the compressed data, it decompresses all the data.
13. During the next cycle R2, CH chooses the next alternative path from the multi path set, to transmit the data.
14. If all the alternate paths are used, then in the next cycle, again the primary path is selected.

IV. Simulation Results

Energy Efficient Multipath Data Fusion (EEMD) Technique is evaluated through NS2 [21] simulation. A random network deployed in an area of 500 X 500 m is considered. Initially 100 sensor nodes are placed in square grid area by placing each sensor in a 50x50 grid cell. 10 cluster heads are deployed in the grid region according to our protocol. The sink is assumed to be situated 100 meters away from the above specified area. In the simulation, the channel capacity of mobile hosts is set to the same value: 2 Mbps. The simulated traffic is CBR with UDP source and sink. The number of sources is per cluster is varied fro 1 to 4.

Table 1 summarizes the simulation parameters used

Table 1: Simulation Parameters

No. of Nodes	100
Area Size	500 X 500
Mac	802.11
Routing protocol	EEMD
Simulation Time	50 sec
Traffic Source	CBR
Packet Size	512 bytes
Rate	100 to 300kb
Transmission Range	150m
No. of Sources per cluster	1 to 4
Transmit Power	0.395 w
Receiving power	0.660 w
Idle power	0.035 w
Initial Energy	5.1 Joules
No. of clusters	10

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A. Performance Metrics

The performance of EEMD technique is compared with the compressive data gathering (CDG) technique [20]. The performance is evaluated mainly, according to the following metrics.

- **Average end-to-end delay:** The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.
- **Average Packet Delivery Ratio:** It is the ratio of the number .of packets received successfully and the total number of packets transmitted.
- **Energy:** It is the average energy consumed for the data transmission.

B. Results

A. Based on Rate

In our initial experiment, we vary the transmission sending rate as 100,150,200, 250 and 300 Kb for CBR traffic. We keep 4 sources per cluster.

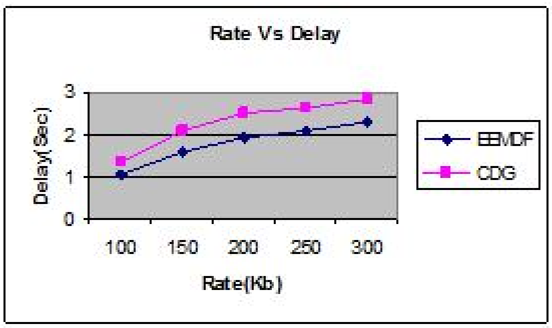

Figure 4. Rate Vs Delay

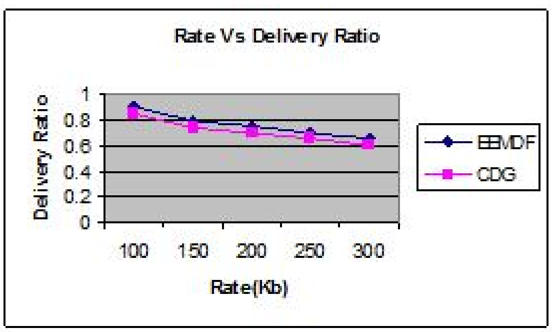

Figure 5. Rate Vs Delivery Ratio

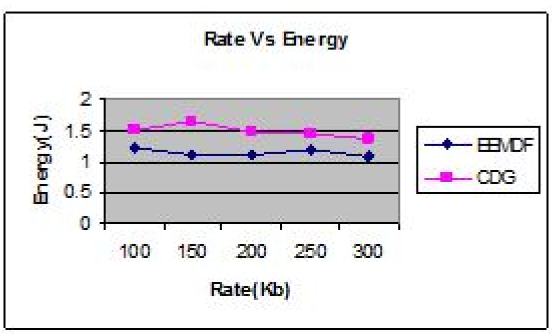

Figure 6. Rate Vs Energy

Figure 4 gives the average end-to-end delay when the rate is increased. It shows that our proposed EEMDF protocol has lower delay when compared to CDG.

Figure 5 gives the packet delivery ratio when the rate is increased. It shows that our proposed EEMDF protocol achieves good delivery ratio when compared to CDG.

Figure 6 gives the energy consumption when the rate is increased. It shows that our proposed EEMDF protocol utilizes lower energy when compared to CDG.

B. Based on Sources

In our second experiment, we vary the no. of sources per cluster from 1 to 4, keeping the CBR sending rate as 100kb.

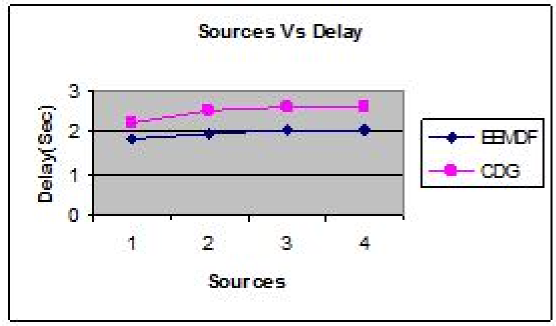

Figure 7. Sources Vs Delay

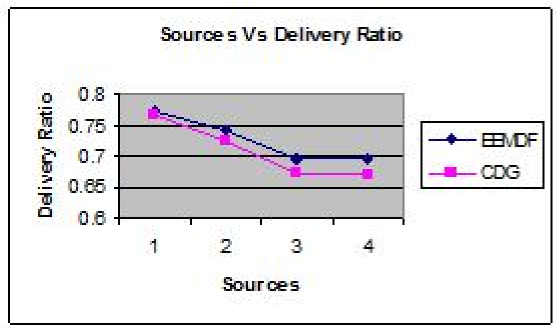

Figure 8. Sources Vs Delivery Ratio

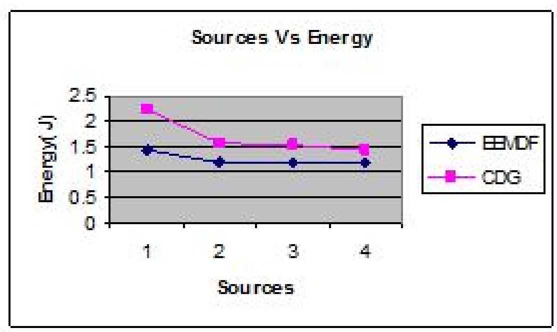

Figure 9. Sources Vs Energy

Figure 7 gives the average end-to-end delay when the no. of source is increased. It shows that our proposed EEMDF protocol has lower delay when compared to CDG.

Figure 8 gives the packet delivery ratio when the no. of source is increased. It shows that our proposed EEMDF protocol achieves good delivery ratio when compared to CDG.

Figure 9 gives the energy consumption when the no. of source is increased. It shows that our proposed EEMDF protocol utilizes lower energy when compared to CDG.

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V. Conclusion

In this paper, we have proposed a technique which combines the energy efficiency and the multiple path selection for data fusion in WSN. We have selected the node with highest residual energy as the cluster head. Randomly selected initiator nodes collect the information of the nearest sensor nodes and select the node with highest energy as the cluster head. The node with the next higher energy level is taken as the initiator. The sink computes multiple paths to each cluster head for data transmission. Each CH uses distributed source coding and the lifting scheme wavelet transform for compressing the data and after the sink receives all the collected data, it will decompress all the data.. Initially the path with minimum number of hops is considered as the primary path and the compressed data is transmitted to the sink through this path. During each round of transmission, the path is changed in a round robin manner, to conserve the energy. This process is repeated for each cluster. From our simulation results we have shown that this data fusion technique has less energy consumption with increased packet delivery ratio, when compared with the existing schemes.

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